Analysis of pavement management activities programming by particle swarm optimization

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Abstract— **The application of particle swarm optimization (PSO) to programming of pavement maintenance activities at the network level is demonstrated. The application of the PSO technique and its relevance to solve the programming problem in a pavement management system (PMS) are discussed. The robust and quick search capability of PSO enable it to effectively handle the highly constrained problem of pavement management activities programming, which has an extremely large solution space of astronomical scale. Examples are presented to highlight the versatility of PSO in accommodating different objective function forms. This versatility makes PSO an effective tool for planning in PMS. It is also demonstrated that composite objective function that combine two or more different objects can be easily considered. PSO find near-optimal solutions besides the "best" solution. This has practical significance as it gives the users the flexibility to examine the suitability of each solution when practical constraints and factors not included in the optimization analysis are considered.**

Keywords **: Particle Swarm Optimization, Pavement Management System, Optimization**

I.Introduction

The traditional methods of pavements management system (PMS) programming activities based on ranking methods or subjective priority rules do not guarantee an optimal or near-optimal utilization of available resources [2]. This is because the number of pavement management activities required to be carried out at the network level are innumerous, and an optimization analysis is required to identify a pavement management program that would achieve an optimal or near-optimal utilization of available resources.

The highway engineer responsible for maintaining a road network is interested in identifying the pavement-management program [1] that could be the best for PMS. Intelligent PMS Optimization method illustrated by FWA in 1996 with genetic algorithm[1]. They show that GA can satisfy PMS parameters and can be used as excellent operator for managing rehabilitation. A pavement maintenance-rehabilitation program at the network level would contain the following information: (1) The time and type of maintenance or rehabilitation (including the do-nothing option) for every pavement segment over the entire planning time period;(2) the resource allocation by time and pavement segment ;and (3)the total commitment of resources for each time period [1]. These parameters made optimal programming of PMS complicated.

The common road-network system objective specified by highway agencies include the following :(1) To minimize the present worth of overall maintenance and rehabilitation expenditures over the planning horizon ; (2)to minimize road-user costs by selecting and programming maintenance and rehabilitation activities to reduce disruption and delays to traffic;(3)to maintain the highest possible level of overall network pavement condition with the resources available [1] . It is also possible to combine two or more of these objectives by assigning an appropriate weight factor to each object.

The novel model in using PSO method for PMS is presented in this research and this is the first time that PSO is using in PMS. The purpose of this research is to determine the best rehabilitation-maintenance activity with PSO , and the cost of the activity is our decision parameter, so the input data must be defined firstly after that PSO model calculates the pavement segment's distress according to deterioration function and checks warning level, and finally with cost function determine the minimal rehabilitation activity. By using FWA cost function [1] we verify our model with FWA model and the results was same and satisfying . In this paper four cost functions with different item were chosen. The minimal rehabilitation cost for hypothetical problem of road network consisting of 15(3 km length for each) segment pavement using particle swarm optimization is determined.

In section II the structure of particle swarm optimization(PSO) is discussed, In section III the input parameter for PSO are illustrated, and is followed by the cost option presented in section IV, In section V the numerical

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results of model are shown. Finally the results and conclusions of the study are reported and discussed in section VI.

II. Particle Swarm Optimization (PSO)

PSO is a global optimization technique that has been developed by Eberhart and Kennedy in 1995[7], The underlying motivation of PSO algorithm was the social behavior observable in nature, such as flocks of birds and schools of fish order to guide swarm of particles towards the most promising regions of the search space. PSO exhibits a good performance in finding solution to static optimization problems. It exploits a population of individuals to synchronously probe promising regions of the search space. Each particle in the swarm represents a candidate solution to the optimization problem. In a PSO system, each particle moves with an adaptable velocity through the search space, adjusting its position in the search space according to own experience and that of neighboring particle, then it retains a memory of the best position it ever encountered, a particle therefore makes use of the best position encountered by itself and the best position of neighbors to position itself towards the global minimum. The effect is that particles "fly" towards the global minimum, while still searching a wide area around the best solution, [8,12,9]. The performance of each particle (i.e. the "closeness" of a particle to the global minimum) is measured according to a predefine fitness function which is related to the problem being solved.

The iterative approach of PSO can be described by the following steps:

Step 1 initializing a population size, positions and velocities of agents, and the number of weights and biases.

Step 2 the current best fitness achieved by particle p is set as p_{best}. The p_{best} with best value is set as g_{best} and this value is stored.

Step 3 Compare the evaluation fitness value f_p for each particle.

Step 4 Compare the evaluated fitness value f_p of each particle with its p_{best} value, If $f_p < p_{best}$ then $p_{best} = f_p$ and $best_{xp} = x_p$, x_p is the current coordinates corresponding to particle p's best fitness so far.

Step 5 The objective function value is calculated for new positions of each particle. If a better position is achieved by an agent, p_{best} value is replaced by the current value. As in step 1, g_{best} value is selected among p_{best} values. If the new g_{best} is better than previous g_{best} value, the g_{best} value is replaced by the current g_{best} value and this value is stored. If $f_p < g_{best}$ then $g_{best} = p$, where g_{best} is the particle having the overall best fitness over all particle in the swarm.

Step 6 change the velocity and location of the particle according to Equation 1 and 2, respectively [7,10].

Step 7 Fly each particle p according to Equation 3.

Step- 8 If the maximum number of a predetermined iterations is exceeded then stop; otherwise loop to step 3 until convergence. In this work, 15 population of weights were evolved for 100 generations with w=0.7.

$$V_i = w.\ V_{i-1} + c_1.rand*(best_{xp} - xp) + c_2.rand(best_{xgbest} - xp) \quad (1)$$

where c1,c2 is the acceleration constant that controls how far particles fly from one another, and *rand* returns a uniform random number between 0 and 1.

$$x_p = x_{pp} + v_i \quad (2)$$

v_i is the current velocity, v_{i-1} is the previous velocity, x_p is the present location of the particle, x_{pp} is the previous location of the particle, and i is the particle index in step 5 the coordinates $best_{xp}$ and $best_{xgbest}$ are used to pull the particles towards the global minimal. In fig 1. the plan of PSO is presented.

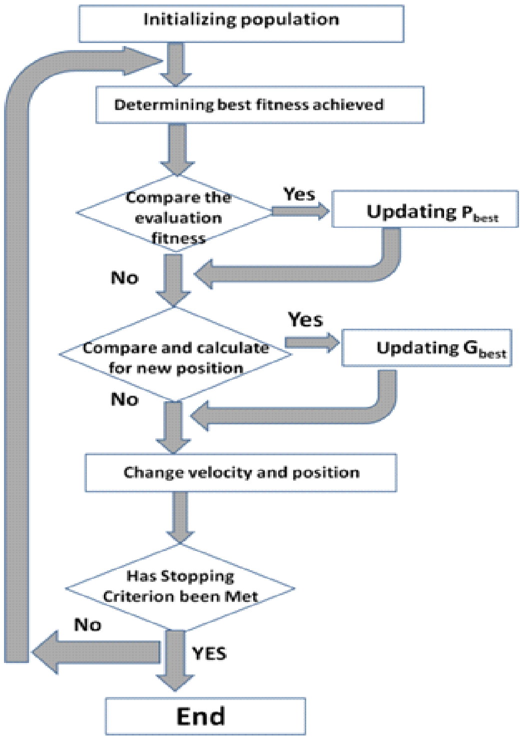

Figure.1 : The plan of PSO

III. The Input Parameters

Pavement network with 15 segments with 3 km length for each segments is assumed, the input parameters are summarized in table I [1]. The age of the pavement segments given in Fig 3 are randomly assigned by assuming a normal distribution [1]. The age of pavement is computed from the time the last structural overlay was laid, or from the time of construction if the pavement has never been overlaid. The total length of the study period is 15 years. The unit planning period is one year.

In this research, the uncertainty of predicted pavement condition is assumed to be associated with random traffic loads. It is assumed here that the uncertainty of future traffic loads are several magnitude larger than other sources of uncertainty. The predicted annual traffic load is a random variable so the predicted pavement performance, which takes the effect of maintenance activity into account, becomes a random variable as well, [3].

Distress parameters include the types of distress considered and their deterioration function. The deterioration

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functions predict distress development with time or traffic loading. maintenance and rehabilitation parameters identify the pavement repair methods used and their costs. Unfortunately, the accuracy of the predicted pavement condition could be influenced by the choice of prediction model,[4] as well as the accuracy of inputs of the deterioration model, [3] like the warning level. A warning level refers to the pavement condition level that the pavement rehabilitation activity must be performed before its specified warning level is reached, or at the latest, when the warning level is reached. Fig.2 presents the research process. Regarding the input data, deterioration function and warning levels, the program determine the essential rehabilitation activity needed for each segment per year. Then according to cost function, the network rehabilitation cost is calculated and finally, PSO determines the best rehabilitation activity (with minimal cost) in network level pavement for 15 years.

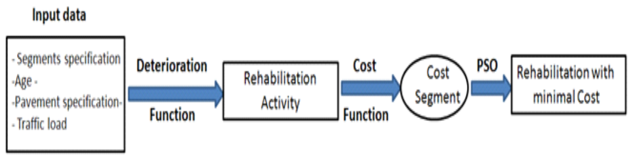

Figure.2 : General Methodology of Article

TABLE.I : THE INPUT DATA

Parameter category	Parameter adopted
Warning Levels	
Cracking Rutting Surface disintegration Structural damage	0.8 m of cracks per km per lane 15 mm rut depth 20% of wheel-path area affected Present serviceability index = 2.5
Resources	
Budget	US$ dollar with 0.6 fixed growth rate
Manpower Equipments	Unlimited Unlimited

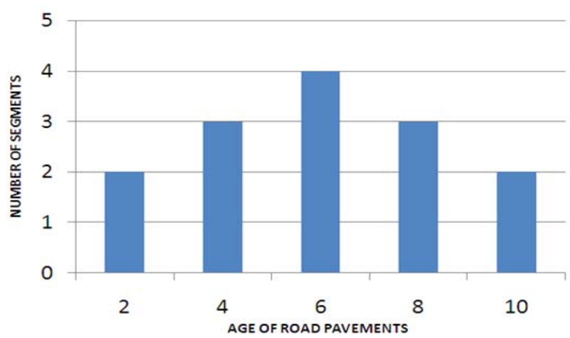

Fig.3 : Age Distribution of Pavement Segments

For simplicity, only three main pavement distress types are considered. They are cracking, rutting, and disintegration of pavement surface materials. [1] For the case of structural damage requiring rehabilitation, the decision to overlay construction is dependent on the present serviceability index (PSI). [11]

Cracking $C=21600*(N)(SN)^{-SN}$ (3)

Rutting $R=4.98*(Y)^{0.166}(SN)^{-0.50}(N)^{0.13}$ (4)

Surface disintegration $S=80*(e^{2.2677*N}-1)$ (5)

$PSI=5.10-1.9*\log(1+SV)-0.01*C^{0.5}-0.00214R^2$ (6)

Where$SV=68.5*((N.10^6)/p)^{\hat{a}}+1.83$ (6a)

$\mathrm{Log}(p)=9.36*\log(SN+1)-0.20$ (6b)

$\hat{a}=0.4+1094/(SN+1)^{5.19}$ (6c)

where C=total area cracked in m^2/km/lane ;N=traffic loading in million passes of equivalent 80 KN single axle; SN= structural number ;R=rut depth in mm ; Y=age of pavement in years ; S=total surface disintegrated in m^2/km/lane.

The resource parameters defines what are commonly known as constraints in optimization problems. Typical planning constraints in pavement management are availability of resources such as budget, manpower, materials, and equipment. Finally, The traffic parameters provide the necessary information for traffic loading to be computed for the entire planning period.

The identifies alternative permitted parameters for repair activities is given in table II. [1] :

IV.Cost Function

A factor that directly influences the outcome of the maintenance-rehabilitation trade-off analysis is the relative costs of rehabilitation and maintenance activities. We have three maintenance activities considered in this study and we can have plenty of rehabilitation. In this paper we mention four rehabilitation strategy that is used in Iran and their cost is listed in table III (all cost values based on Iran exchange in US dollar (US$)). The discount rate used in the analysis is 6%.

TABLE.II : THE LIST OF REPAIR ACTIVITIES

Required activity	Alternative Repair Activity								
	O[0]	I[1]	II[2]	III[3]	IV[4]	V[5]	VI[6]	VII[7]	VIII[8]
O	O	O	O	O	O	O	O	O	O
I	-	O	-	-	-	-	-	-	
II	-	O	O	-	-	O	O	-	O
III	-	O	-	O	-	O	-	O	O
IV	-	O	-	-	O	-	O	O	O
V	-	O	-	-	-	O	-	-	O
VI	-	O	-	-	-	-	O	-	O
VII	-	O	-	-	-	-	-	O	O
VIII	-	O	-	-	-	-	-	-	O

Note : O = permitted alternative for the required activity
0 : No action required
1 : Rehabilitation
2 : Crack sealing
3 : Premix leveling
4 : Patching
5 : Crack sealing and premix leveling
6: Crack sealing and patching
7 : Premix leveling and patching
8: Crack dealing , premix leveling , and patching

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TABLE .III: THE COST OF REHABILITATION

CASE		Cracking Sealing	Patching	Premix leveling	Overlay
1	Rehabilitation	Slurry seal	Cold asphalt Patching	Tack Coat with Asphalt Emulsion	Hot mix overlay
	cost	18250*C	7336.5	139886.25*S	175930
2	Rehabilitation	Slurry seal	Cold asphalt Patching	Asphalt Emulsion	Hot mix overlay
	cost	18250*C	7336.5	120176.25*S	175930
3	Rehabilitation	Mastic asphalt	Hot asphalt patching	Bitumen Solution	Hot mix overlay
	cost	14600*C	8030	128115*S	175930
4	Rehabilitation	Polymer asphalt	Hot asphalt patching	Bitumen Solution	Hot mix overlay
	cost	5621*C	8030	128115*S	175930
All costs value are in US dollar (US$)					

V.The Numerical Results of Model

The purpose of this model is to find the maintenance-rehabilitation program in pavement network. It shows the time and kind of rehabilitation with minimal cost. By using FWA cost function in the model , result similarity between PSO model and FWA model were achieved . Results of PSO model illustrate pavement rehabilitation and maintenance program for 15 segments during 15 years .

PSO calculated the cost of each part with cost function and compare the costs with each other and selected the best of all. The model started the optimization with 100 particles and randomly selected 15 segments of them. For these segments distress will be calculated and controlled with distress level. After that the maintenance-rehabilitation activity will be determined. Based on activity and table the cost function will be calculated, cumulated cost of each segment is set to P_{best} and compared to G_{best}, and the minimum of them is set to G_{best}. This will be continued 600 times to find the best G_{best}. The last G_{best} and related rehabilitation activity is plotted. (see tables (IV-VII))

The inertia weight was introduced by Shi and Eberhart [13]. As a mechanism to control the exploration and exploitation abilities of the particle, and as a mechanism to eliminate the need for velocity clamping [14].The inertia weight, w, controls the momentum of the particle by weighing the contribution of the previous velocity – basically controlling how much memory of the previous flight direction will influence the new velocity.

The value of w is extremely important to ensure convergent behavior, and to optimally tradeoff exploration and exploitation. For we”1, velocities increase over time, accelerating towards the maximum velocity (assuming velocity clamping is used), and the swarm diverges. Particles fail to change direction in order to move back towards promising areas. For w < 1, particles decelerate until their velocities reach zero. Large values for w facilitate exploration, with increased diversity. However, too small values eliminate the exploration ability of the swarm. Little momentum is then preserved from the previous time step, which enables quick changes in direction. As with the maximum velocity, the optimal value for the inertia weight is problem dependent [14]. In this model we assumed w as 0.7 it means our particle started with 15 segments out of 100 which decreases over time to smaller values. At this time it is crucial to mention the important relationship between the values of w, and the acceleration constants. The choice of value for w has to be made in conjunction with the selection of the values for c1 and c2 [15,16] that showed in eq.7

$$\omega > 0.5 * (X1 + X2) - 1 \qquad (7)$$

guarantees convergent particle trajectories. If this condition is not satisfied, divergent or cyclic behavior may occur.

The solution to the four cases of the problem present interesting trade-off scenarios between rehabilitation and maintenance. These solution provide the complete program of repair activities by year and by pavements segment for the four cases. All solutions satisfy the pavement performance requirements that distress conditions and pavement are kept above their respective warning levels throughout the 15-year analysis period. In table VIII the cost of rehabilitation activities in four cases are illustrated. Now with PSO model we can make decision and choosing the best rehabilitation-maintenance strategy. In this research we use four cost function with different activity such as cold asphalt, polymer, emulsion and hot mix asphalt according our budget, manpower and resources we can use each of them. The cost of maintenance and rehabilitation program for the case 1 and 2 is equal but its cost function treatment items are different (premix leveling in case 1 tack coat with asphalt emulsion but in case 2 asphalt emulsion) so one can be selected base on performance situation and manpower.

TABLE VIII. WORTH OF TOTAL COST OF REHABILITATION AND MAINTENANCE

case	Total cost over 15 years
I	3,219,400
II	3,219,400
III	2,795,400
IV	1,578,700

VI.Conclusion

This paper presented the formulation of a PSO as program for pavement management system in network level, This is the first time that using PSO model for optimizing pavement system activities . Numerical examples were presented using four cases of a hypothetical problem, each with different relative costs of rehabilitation and maintenance activities, to demonstrate the trade-off relationship between pavement rehabilitation and maintenance activities and it shows that PSO is suitable for pavement management in network level.Regarding the cost of rehabilitation and maintenance program in network level and according the performance limitation and manpower , the optimum program can be selected.

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TABLE. IV . SCHEDULED REHABILITATION AND MAINTENANCE ACTIVITIES FOR SOLUTION OF CASE I

pavement segments	year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	5	5	5	5	5	5	8	8	8	8	6	6	6	4	4
2	5	5	5	5	5	2	2	2	5	5	2	2	2	0	0
3	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
4	5	5	5	5	5	8	8	8	8	8	8	8	8	4	7
5	5	5	5	5	5	8	8	8	8	8	8	8	8	7	7
6	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0
7	5	8	8	8	8	8	8	8	8	8	8	8	8	7	7
8	5	5	5	5	5	5	5	5	5	5	5	5	5	0	3
9	5	5	5	8	8	8	8	8	8	8	8	8	8	7	7
10	5	5	5	5	8	8	8	8	8	8	8	8	8	7	7
11	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
12	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
13	1	1	8	1	1	8	8	1	1	1	8	1	1	8	8
14	5	5	5	5	5	5	5	5	5	5	5	8	8	7	7
15	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3

note:0=NO action; 1=overlay ;2=crack sealing ;3=premix leveling ;4=patching 5=crack sealing and premix leveling ;6= crack sealing and patching ;7=premix leveling and crack sealing ;8=crack sealing patching and premix leveling

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TABLE V. SCHEDULED REHABILITATION AND MAINTENANCE ACTIVITIES FOR SOLUTION OF CASE II

pavement segments	year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	5	5	5	5	5	2	2	2	2	2	2	2	2	0	0
2	5	5	8	8	8	8	8	8	8	8	8	8	8	4	4
3	5	5	5	8	8	8	8	8	8	8	8	8	8	4	4
4	5	5	5	5	5	5	8	8	8	8	8	8	8	4	4
5	5	5	5	5	8	8	8	8	8	8	8	8	8	7	7
6	8	1	8	8	8	8	8	8	8	8	8	8	8	8	8
7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
8	5	5	5	5	5	8	8	8	8	8	8	8	8	7	7
9	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
11	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
12	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
13	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
14	5	5	5	5	5	5	5	5	5	8	8	8	8	7	7
15	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3

note:0=NO action 1=overlay 2=crack sealing 3=premix leveling 4=patching 5=crack sealing and premix leveling 6= crack sealing and patching 7=premix leveling and crack sealing 8=crack sealing patching and premix leveling

TABLE VI. SCHEDULED REHABILITATION AND MAINTENANCE ACTIVITIES FOR SOLUTION OF CASE III

pavement segments	year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	5	5	5	5	5	2	2	2	2	2	2	2	2	0	0
2	5	5	8	8	8	8	8	8	8	8	8	8	8	4	4
3	5	5	5	8	8	8	8	8	8	8	8	8	8	4	4
4	5	5	5	5	5	5	8	8	8	8	8	8	8	4	4
5	5	5	5	5	8	8	8	8	8	8	8	8	8	7	7
6	8	1	8	8	8	8	8	8	8	8	8	8	8	8	8
7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
8	5	5	5	5	5	8	8	8	8	8	8	8	8	7	7
9	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
11	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
12	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
13	1	1	1	1	1	1	1	1	1	1	1	1	1	8	8
14	5	5	5	5	5	5	5	5	5	8	8	8	8	7	7
15	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3

note:0=NO action 1=overlay 2=crack sealing 3=premix leveling 4=patching 5=crack sealing and premix leveling 6= crack sealing and patching 7=premix leveling and crack sealing 8=crack sealing patching and premix leveling

TABLE VII. SCHEDULED REHABILITATION AND MAINTENANCE ACTIVITIES FOR SOLUTION OF CASE

pavement segments	year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	5	5	5	5	8	8	8	8	8	8	6	8	8	4	4
2	5	5	5	5	5	5	5	5	5	8	6	8	8	4	4
3	5	5	5	5	5	5	5	5	5	5	2	2	2	0	0
4	5	5	5	5	5	5	5	5	5	5	2	2	5	0	0
5	5	5	5	5	5	5	5	5	5	5	5	5	8	4	4
6	5	5	5	5	5	5	5	5	5	5	5	5	8	4	7
7	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0
8	1	1	8	1	1	8	8	1	1	1	8	8	1	8	8
9	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
10	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3
11	5	5	5	5	8	8	8	8	8	8	8	8	8	7	7
12	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
13	5	5	8	8	8	8	8	8	8	8	8	8	8	7	7
14	8	1	8	8	8	8	8	8	8	1	8	8	8	8	8
15	5	5	5	5	5	5	5	5	5	5	5	5	5	3	3

note:0=NO action 1=overlay 2=crack sealing 3=premix leveling 4=patching 5=crack sealing and premix leveling 6= crack sealing and patching 7=premix leveling and crack sealing 8=crack sealing patching and premix leveling

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